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ABSTRACT

As a supplement to the principal reports, a total of 776 verbal behavioral objectives are incorporated in this document relating to the U. S. Naval Academy Self-Paced Physics Course. The objectives are related to the following aspects: physical measurements, frames of reference, significant figures, statics, dynamics, kinematics, electricity, and magnetism. All are on the level of the Halliday and Resnick physics textbook. (Related documents are SE 016 065 through SE 016 088 and ED 062 123 through ED 062 125.) (CC)

01 1 001 00 solve problems which involve converting and otherwise manipulating units of length and time in the most common systems of measurement.

01 1 001 01 name invariability as the more important criterion for selecting standards of measurement than accessibility in cases where these criteria are incompatible.

01 1 001 02 define a fundamental quantity as used in physics.

01 1 001 03 select, from a list of four physical quantities, the one that is not a fundamental (is a derived) quantity.

01 1 001 04 state the historical definition of the meter based upon the circumference of the earth.

01 1 001 05 select, from a list of four statements, the one that gives sharpness and narrowness as the reasons the orange-red line of krypton 86 was chosen for the definition of the modern meter.

01 1 001 06 deduce the relationship between the nautical mile and the meter (1 n.m. = 1852 m), using the historical definitions of both.

01 1 001 07 define the sidereal day and be able to state its relationship to the mean solar day.

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01 1 001 23 define a derived quantity as used in physics.

01 1 001 25 define the standard meter in terms of the wavelength of the orange-red line in the spectrum of krypton 86.

01 1 001 26 use the fact that a circle consists of $60 \times 360 = 21600$ minutes of arc.

01 1 002 00 answer fundamental verbal questions relating to frames of reference.

01 1 002 01 select, from a list of four statements, the one that gives both time and position as relative quantities; i.e., they have no absolute frame of reference.

01 1 003 00	select, and carry from data to answer, the correct number of significant digits in all types of arithmetic operations.
01 1 003 01	select, from a list of numbers, the ones that have the same number of significant figures.
01 1 003 02	give the number of significant figures that must be retained in a sum of many numbers, each with a different number of significant figures.
01 1 003 03	select the correct way that the area of a rectangle (product of two numbers) must be written, in order to have the right number of significant figures.
01 1 003 04	select the correct way that the volume of a sphere (product of three variable numbers) must be written, in order to have the right number of significant figures.

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01 1 003 24	recognize that constant factors (for example the factor 4/3 in the expression for the volume of a sphere) have unlimited numbers of significant figures, and that constants like π are known to a very high degree of accuracy.

01 1 004 00	manipulate vectors, and recognize that physical quantities which must be specified by a magnitude and a direction are vector quantities.
01 1 004 01	compute the dot product of two vectors.
01 1 004 02	compute the cross (vector) product of two vectors.
01 1 004 03	recognize that displacement is a vector quantity and must be treated as such.
01 1 004 04	recognize that the area of a parallelogram is equal to the magnitude of the cross product of its two adjacent sides taken as vectors.
01 1 004 05	determine the triple product, $(\vec{A} \times \vec{B}) \cdot \vec{C}$, of three co-planar vectors $\vec{A}$, $\vec{B}$ and $\vec{C}$.

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01 1 004 22	recognize that the cross product is a vector, and find the direction of this vector.

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01 1 004 81	distinguish between scalar and vector quantities by selecting the scalars (or vectors) from a list of physical quantities.
01 1 004 82	add and subtract vectors.
01 1 004 83	identify the mathematical laws (commutative, distributive, associative) which are obeyed by the various vector operations (addition, dot product, cross product).
01 1 004 84	recognize that the cross product of a vector and a scalar is meaningless.

01 2 005 00 define and use the terms needed in the study of kinematics.

01 2 005 01 distinguish between the terms "kinematics" and "dynamics" in any verbal problem.

01 2 005 02 define a particle as a body having mass but zero extension in space.

01 2 005 03 define translational motion as motion of a body in which all its particles move along parallel lines, and apply this definition in selecting from a list of graphs that graph which represents a translation.

01 2 005 04 recognize that translational motion need not be linear.

01 2 006 00 solve problems involving rectilinear motion with constant acceleration.

01 2 006 01 calculate the average velocity for constant acceleration as the ratio of the vector displacement to the time elapsed during which the displacement is traversed.

01 2 006 02 compute the velocity of a particle at a given time, given the displacement of the particle as a function of time.

01 2 006 03 recognize that the acceleration of a body is not zero whenever its (vector) velocity changes, even though the magnitude of the velocity (speed) may remain the same.

01 2 006 04 compute the average acceleration, given the initial and final velocities (magnitudes and directions) and the time during which the velocity change takes place from

$$\vec{a} = \Delta\vec{v}/\Delta\vec{t} = (\vec{v}_f - \vec{v}_i)/\Delta t.$$

01 2 006 05 convert acceleration from one system of units to another.

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01 2 006 21 recognize that velocity is a vector quantity.

01 2 006 22 define velocity as the time rate of change of position ($\vec{v} = d\vec{r}/dt$).

01 2 006 23 define acceleration as the time rate of change of velocity ($\vec{a} = d\vec{v}/dt$).

01 2 006 31 use the relationships among the various units of time (hours, minutes, seconds, etc.) to convert from one unit to the other.

01 2 006 33 recognize that the acceleration is a vector quantity.

01 2 006 41 use the relationships among various units of length (meter, cm, foot, inch, mile, etc.) to convert from one unit to the other.

01 2 006 51 convert velocity (or speed) from one system of units to another. (Some common units used in this course: mph, ft/s, m/s, cm/s, km/h, knot, etc.)

01 2 007 00 interpret graphs having time as abscissa and position, velocity, or acceleration as ordinate, and solve problems involving these quantities using the information supplied by the graphs.

01 2 007 01 solve for the average velocity in the x-direction, given an x versus t curve; from

$$\overline{v}_x = \frac{\Delta x}{\Delta t} = \frac{X(t_2) - X(t_1)}{t_2 - t_1} .$$

01 2 007 02 find point on a v versus t curve at which the acceleration is the same.

01 2 007 03 select from among given graphs the ones that represent variable acceleration.

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01 2 007 22 recognize that the slope at any point of a v versus t curve gives the instantaneous acceleration at that point.

01 2 007 23 recognize that the acceleration is the second derivative of the position with respect to time, i.e.,

$$\vec{a} \equiv \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2} .$$

01 2 008 00	determine whether given equations are plausible by using dimensional analysis.
01 2 008 01	use dimensional analysis to select the only correct equation giving the position of a body as a function of time when the body is subjected to air resistance, from a list of four equations.
01 2 008 21	recognize that the argument of a special function (exponential, logarithmic, trigonmetric, etc.) must be a dimensionless quantity.

01 2 009 00 solve problems dealing with the free fall of bodies (one-dimensional motion) near the surface of the earth by using one of the following equations

$$v_y = v_{oy} + at = v_{oy} - gt \tag{1}$$

$$y = y_o + v_{oy}t - (1/2)gt^2 \tag{2}$$

$$v_y^2 = v_{oy}^2 - 2g\,(y - y_o) \tag{3}$$

$$y = y_o + \bar{v}_y t = y_o + (1/2)\,(v_{oy} + v_y)t \tag{4}$$

01 2 009 01 use (1) to determine any of the quantities involved.

01 2 009 02 use equation (2) to determine any of the quantities involved in it.

01 2 009 03 use equation (3) to determine any of the quantities involved in it.

01 2 009 04 use equation (4) to determine any of the quantities involved in it.

01 2 009 05 use (2) to determine g, when the only given data are in a list giving the distance of fall of a body and the corresponding time at which this distance was measured.

01 2 010 00 solve problems dealing with the concept of relative motion by using the general relative velocity equation,

$$\vec{v}_{ac} = \vec{v}_{ab} + \vec{v}_{bc} \tag{5}$$

or equations derived from it. (Here $\vec{v}_{ab}$ is read: the velocity of body a with respect to body b.)

01 2 010 01 use the above equation to solve for $\vec{v}_{ac}$, given $\vec{v}_{ab}$ and $\vec{v}_{bc}$.

01 2 011 00 use the definition $\vec{v}$ and $\vec{a}$ ($\vec{v} = d\vec{r}/dt$, $\vec{a} = d\vec{v}/dt = d^2\vec{r}/dt^2$), to solve problems involving differentiation or integration.

01 2 011 01 compute the acceleration of a particle at a given time, given the dependence of the particle's position on time.

01 2 011 02 find the time it takes a car to stop, given the initial speed of the car and the time dependence of the magnitude of the deceleration; i.e., integrate the equation

$$dv = a(t)\ dt$$

01 2 011 03 find the distance that the car above travels before coming to a stop, by integrating the equation

$$dx = v(t)\ dt\ ,$$

and using the time found.

01 3 012 00 analyze the t [illegible]ional trajectory of a body projected from any height, at any angle with the horizontal, using the two-dimensional (vector) equations

$$\vec{v} = \vec{v}_o + \vec{a}t \ , \tag{6}$$

$$\vec{r} = \vec{r}_o + \vec{v}_o t + \frac{1}{2}\vec{a}t^2 \ , \tag{7}$$

$$v^2 = v_o^{\ 2} + 2\vec{a}\cdot(\vec{r} - \vec{r}_o) \quad \text{and} \tag{8}$$

$$r = \frac{1}{2}(\vec{v} + \vec{v}_o)\ t \ , \tag{9}$$

with $a_x = 0$, $a_y = -g =$ constant.

01 3 012 01 compute the highest altitude that a body projected from ground level attains, given the initial velocity.

01 3 012 02 compute the time it takes a projectile to attain its highest altitude.

01 3 012 03 recognize that the horizontal velocity of a projectile remains constant, and use this to determine the horizontal position at any time.

01 3 012 04 show that when a body, projected at an angle above the horizontal returns to its initial position its vertical velocity is equal in magnitude and opposite in direction to its initial velocity.

01 3 012 05 determine the horizontal range of projectile.

01 3 012 06 calculate the maximum range of a cannon.

01 3 012 07 compute the angle of projection, given the range and initial speed.

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01 3 012 21 analyze the position, velocity and acceleration vectors into their x- and y-components; i.e.,

$$\vec{r} = x\hat{i} + y\hat{j}$$

$$\vec{v} = v_x\hat{i} + v_y\hat{j}$$

$$\vec{a} = a_x\hat{i} + \vec{v}_y\hat{j}$$

01 3 012 27 recognize that a horizontal range, less than the maximum one, can be attained with two angles of projection.

01 3 012 31 recognize the independence of the vertical and horizontal motion of a projectile.

01 3 012 41 recognize that when the projectile reaches its highest altitude, the vertical component of its velocity is momentarily zero.

02 1 013 00 apply Newton's first law of motion.

02 1 013 01 recognize that every body persists in its state of uni[illegible] motion in a straight line unless it is [illegible] to change that state by forces im[illegible] it.

02 1 013 02 calculate the speed of a particle after an interval of time in the absence of net exterior force.

02 1 013 03 recall that forces are vector quantities.

02 1 013 04 recognize that a particle moving at constant velocity has zero net force acting upon it.

02 1 013 05 draw all the forces acting on a block in motion.

02 1 013 06 isolate forces on a free-body diagram.

02 1 013 07 recognize that the normal force is not always equal to the weight.

02 1 013 08 demonstrate that Newton's first law is independent of the reference frame.

02 1 013 09 calculate each force acting on a particle when the net force is zero.

02 1 013 10 recognize that mass is an intrinsic property of matter that determines its resistance to a change in motion.

02 1 013 11 choose the pound, the foot, and the second to be fundamental units.

02 1 013 12 demonstrate that a massless string transmits a force unchanged.

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02 1 013 23 recognize the meaning of scalar and vector quantities.

02 1 013 26 realize that all forces acting on a body are drawn through the center of mass.

02 1 013 27 rotate vectors into their x- and y-components.

02 1 013 28 demonstrate that two moving objects stuck together have zero relative velocity.

02 1 013 29 solve simultaneous equations.

02 1 014 00	apply Newton's second law of motion.
02 1 014 01	write Newton's second law in component form in three dimensions.
02 1	[illegible]strate that the acceleration of a mass is directly proportional to the net force acting upon it.
02 2 014 03	draw a free-body diagram to isolate individual parts of an accelerating system.
02 2 014 04	choose the correct free-body diagram for a moving block acted upon by a string.
02 2 014 05	demonstrate the use of a sign convention for the direction of vectors.
02 2 014 06	use friction force in a free-body diagram of a moving body.
02 2 014 07	use friction force, tension and [illegible]ight in a free-body diagram to determine the [illegible]eration of a body.
02 2 014 08	recognize that the normal force depends upon the motion of a body.
02 2 014 09	determine the tension in the string of an Atwood's machine at rest.
02 2 014 10	determine the tension in the string of an Atwood's machine in motion.
02 2 014 11	solve a problem with two pulleys and a massless string.
02 2 014 12	solve a problem involving multiple pulleys and a massless string.
02 2 014 13	determine the force required to accelerate an object given initial and final velocities and distance travelled.
02 2 014 14	determine displacement if given the force as a function of time.

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02 1 014 21	demonstrate how to resolve vectors.

02 2 014 25 recognize that a massless pulley merely changes the direction of a force.

02 2 014 29 draw an Atwood machine.

02 1 015 00	delineate the difference between mass and weight.
02 1 015 01	define the weight of a body near the earth as the attractive force exerted on the body by the earth.
02 1 015 02	calculate the vertical acceleration of a body due to its weight alone.
02 1 015 03	determine the weight of an object near the moon.

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02 1 015 21	realize that two masses attract each other.
02 1 015 22	realize that weight is a force.
02 1 015 23	locate the published value for : ss of the moon.

02 1 016 00 apply Newton's third law of motion.

02 1 016 01 state Newton's third law of motion.

02 1 016 03 recognize that at least two bodies are always involved for a force to exist.

02 1 016 04 recognize that, when two bodies exert forces on each other, either of the two forces may be considered the reaction force.

02 2 017 00	use the coefficient of friction to solve problems of motion.
02 2 017 01	recognize that the coefficients of friction are empirical.
02 2 017 02	recognize that kinetic friction is proportional to the normal force.
02 2 017 03	recognize that kinetic friction is independent of the area of surface contact.
02 2 017 04	recall that the force of friction always acts in a direction opposite to the direction of motion.
02 2 017 05	realize that the coefficient of kinetic friction is less than the coefficient of static friction.
02 2 017 06	calculate the coefficient of static friction experimentally.
02 2 017 07	show that the force of static friction can be used to suspend a block from a verticle wall.
02 2 017 08	realize that the force of friction can be the force used to accelerate a block.

02 3 018 00	describe the kinematic parameters of a particle in circular motion.
02 3 018 01	recognize that, when a particle moves in a circular path with constant speed, it is accelerating due to the change in direction of the velocity.
02 3 018 02	define uniform circular motion.
02 3 018 03	recognize that the radial acceleration is equal to v^2/r, where v is the magnitude of the tangential velocity.
02 3 018 04	define centripetal.
02 3 018 05	realize that velocity can change by a change in direction alone.
02 3 018 06	determine an expression for the distance traveled by a particle undergoing uniform circular motion.
02 3 018 08	calculate the radial acceleration from $a = v^2/r$.
02 3 018 09	calculate the number of revolutions per minute given the tangential velocity of a wheel.
02 3 018 10	determine the relative velocity of the rim of a wheel with respect to the center of the wheel.
02 3 018 11	recognize that the tangential velocity of a wheel varies linearly with the radius.
02 3 018 12	determine the time required for an orbiting body to make one revolution.

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02 3 018 27	recall that when two triangles are similar, the ratios of the corresponding sides are equal.

02 3 019 00	apply centripetal force to problems of circular motion.
02 3 019 01	recognize when a centripetal force must be applied.
02 3 019 02	recall that an orbiting satellite has only one force acting--its weight.
02 3 019 03	recall that the centripetal force can be calculated from $F = mv^2/r$.
02 3 019 04	calculate the centripetal force using $F = mv^2/r$.
02 3 019 05	use Newton's second law and the relationship for centripetal force.
02 3 019 06	combine circular motion and linear motion problems.

03 1 020 00	answer fundamental questions and solve problems pertaining to the work done by a constant force (graphically and analytically).
03 1 020 01	solve one-dimensional problems for the work done by a constant force acting on a particle.
03 1 020 02	identify the force-versus-displacement graph which represents a constant force.

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03 1 020 21	define the work done by a constant force (acting on a particle) when the force and the particle displacement are in the same direction ($W = F_s s$).

03 1 021 00 use the definition of work,

$$W_{12} = \int_1^2 dW = \int_{s_1}^{s_2} \vec{F}\cdot d\vec{s} = \int_{s_1}^{s_2} F \cos\theta \, ds = \int_{s_1}^{s_2} F_s ds \quad \ldots (1)$$

to solve problems pertaining to the work done by a variable force.

03 1 021 01 compute the work done by a force whose component along the direction of motion varies linearly with the displacement.

03 1 021 02 use the fact that the integral in (1) is equal to the area under the F_s versus s curve to compute the work done by a varying force, geometrically.

03 1 021 03 use (1) to determine the work done by any force whose dependence on displacement is known directly or indirectly.

03 1 021 04 compute the work done by a spring obeying Hooke's law in moving a mass from one point to another.

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03 1 021 21 use the fact that the integral in (1) is equal to the area under the F_s versus s curve to compute the work done by a varying force geometrically.

03 1 021 24 recognize that a spring obeys Hooke's law, if the force applied by the spring when it is deformed is proportional to the deformation (elongation or compression).

03 1 021 31 recognize that in general work is defined by equation (1) above.

03 1 022 00 define power and solve problems for the power delivered by a mechanical system.

03 1 022 01 derive the expression $P = \vec{F} \cdot \vec{v}$, for the instantaneous power delivered by a force $\vec{F}$ applied on a particle when the particle is moving with a velocity $\vec{v}$, and use it to solve problems.

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03 1 022 21 define power as the time rate at which work is being done ($P = dW/dt$).

03 1 022 31 recognize the units of power in the three standard systems as well as the horsepower and convert from one unit to the other.

03 1 022 41 analyze the forces acting on a body on an incline to their parallel and normal components.

03 1 023 00	answer fundamental questions relating to the physical significance of the kinetic energy of a body.
03 1 023 01	use the work-energy theorem to determine the amount of work required to change the speed of a particle to a given value.
03 1 023 02	use the work energy theorem to derive the equation $v^2 = v_o^2 + 2\vec{a}\cdot(\vec{r} - \vec{r}_o)$.
03 1 023 03	use the above equation to compute the speed of a block after it has traveled a given distance along an inclined plane.
03 1 023 04	use the work energy theorem to show that a projectile hits the ground with the same speed with which it is projected (from ground level).
03 1 023 05	use the work energy theorem to determine the kinetic energy of a projectile at its highest altitude.
03 1 023 06	compute the kinetic energy of a moving body from $K = (1/2)mv^2$, making sure to convert to all quantities involved to the appropriate units.
03 1 023 07	use the work-energy theorem to compute the average force acting on a bullet, given the penetration inside a block of wood.

03 2 024 00 analyze events involving conservative and non-conservative (dissipative) forces.

03 2 024 01 give some examples of conservative forces; i.e., the elastic force of an ideal spring, the force of gravity, etc.

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03 2 024 21 define a force $\vec{F}$ as conservative if the work done by it on a particle that moves through any closed path is zero; i.e.,

$$\oint \vec{F}\cdot d\vec{s} = 0 .$$

03 2 025 00	answer fundamental questions and solve problems relating to the nature of mechanical potential energy and the units used to measure it.
03 2 025 01	use the fact that when a conservative force is applied $\Delta K + \Delta U = 0$ to show that $W = -\Delta U$.
03 2 025 02	combine the work-energy theorem, $W = \Delta K$, with the conservative relationship $\Delta K + \Delta U = 0$ to derive the relationship $$(1/2)mv_o^2 + U(x_o) = (-1/2)mv^2 + U(x) .$$
03 2 025 03	recognize that the values of potential and kinetic energies of a system depend on the frame of reference relative to which the position and velocities involved are being measured.

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03 2 025 21	recognize, using the concept of conservative forces, that any change in the kinetic energy of a body, ΔK, must be accompanied by a change in its potential energy, ΔU, such that $\Delta K = -\Delta U$ or $\Delta K + \Delta U = 0$.

03 2 026 0 ... the definition $\vec{F} = -\nabla U$ (or $U = -\int \vec{F}\cdot d\vec{r}$) to ...rmine the force when the potential is given, ...ce versa.

03 2 026 0... ...mine any Cartesian component of the force as ...unction of x, y and z [F_i (x, y, z)], given ... y, z).

03 2 026 02 ...ermine F(r), given U(r).

03 2 026 03 ...grate the expression for the force to find an ...ression for the potential energy.

03 2 026 04 ...ognize that potential energy is a relative ...antity; its value at a point in space depends ...n the choice of the point at which the potential ...ergy is taken to be zero.

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03 2 026 21 ... the partial derivative of a function of more ...n one variable.

0 [illegible]	use the c[illegible] t of conservati[illegible] [illegible]chanical energy to [illegible] various problem[illegible] kinematics where con[illegible]vation of mechanical [illegible]gy is applicable.
[illegible] 01	find the hig[illegible]st point reached b[illegible] a body projected verti[illegible]ally upward.
[illegible] 02	solve probl[illegible] involving motion [illegible] frictionless non-horizontal surfaces.
03 2 027 03	solve problem involving the moti[illegible]n of a simple pendulum.
03 2 027 04	solve problems involving mass-spring systems.
03 2 027 05	solve problems involving motion on surfaces with friction by recognizing the fact that the total mechanical energy is no longer constant but is reduced by an amount equal to the work done against frictio[illegible].
03 2 027 06	solve problems involving motion in a path which includes a circular loop.

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03 2 027 21	recognize that the gravitational potential energy of a body, when the surface of the earth taken as the zero potential level, is given by $U = mgh$ (where h is the altitude of the body).
03 2 027 24	use the fact that for a spring $F = -k(x - x_0)$ along with the definition $U = -\int F_x dx$ to derive the expression for the elastic potential energy of a spring, $U = (1/2)k(x - x_0)^2$.

03 3 028 00 ... r fundamental questions on the concept of ... r of mass, and locate the center of mass of ... s bodies.

03 3 028 01 recognize that the center of mass of a body moves in the same way that a particle of equal mass ... t to the same external forces would move, provided the net external force acting on the body is applied along a line passing through the center of mass.

03 3 028 02 ... fy that the center of mass of a body is a ... fixed relati to the body but not necessarily within the material of the body

03 3 028 03 recognize that the center of mass of a system of two particles lies along the line joining the two particles and its position is the mass-weighted mean of the positions of the two particles.

03 3 028 04 determine the coordinates of the center of mass of a system of particles.

03 3 028 05 recognize that the position of the center of mass of a system of particles does not change if a particle is added to the system at the location of the center of mass.

03 3 028 06 deduce that the position of the center of mass of a system of particles does not change if the masses of the particles are changed proportionately.

03 3 028 07 deduce that the position of the center of mass of a system of particles does not change if the distances of the particles from their center of mass are changed proportionately.

03 3 028 08 determine the center of mass of a symmetrical two dimensional body by recognizing that the center of mass of a homogeneous symmetrical body lies at its geometric center.

03 3 028 09 select the most convenient element of area for determining the center of mass of a body by integrations ($dm = \rho dA$).

03 3 028 10 use integrations to determine the center of mass of a homogeneous triangle.

03 3 029 00 describe the concepts of and solve problems relating to the motion of the center of mass.

03 3 029 01 determine the acceleration of the center of mass of a system of two particles acted upon by given forces.

03 3 029 02 recognize from Newton's third law that internal forces cancel out in pairs and hence their removal does mot affect the motion of the center of mass.

03 3 029 03 define the center-of-mass reference frame, and compute the kinetic energy of a system of particles relative to their center of mass frame.

04 1 030 00 solve momentum problems involving ... with constant mass.

04 1 030 01 calculate the momentum of a body whose mass and velocity are given.

04 1 030 02 find the magnitude of total momentum of a system of masses with given velocities (or momenta).

04 1 030 03 determine the direction of the total momentum of a system of masses with given velocities (or momenta).

04 1 030 04 find the velocity of the center of mass of a system of masses given the total momentum of the system.

04 1 030 05 use Newton's second law of motion to determine the force exerted on a body, given the rate at which the body's momentum is changing.

04 1 030 06 use Newton's second law of motion to determine the acceleration of a body, given the rate at which the body's momentum is changing.

04 1 030 07 determine the momentum of a body of known mass, given the body's kinetic energy.

04 1 030 08 recognize that the forces involved in the situation above are internal forces; hence, the center of mass remains stationary.

* * *

04 1 030 21 define momentum as a vector quantity equal to the product of the mass and the velocity of a body ($\vec{p} = m\vec{v}$).

04 1 030 25 express Newton's second law of motion in the form

$$\vec{F} = d\vec{p}/dt = m\vec{a}$$

where the last equation holds only for constant mass.

04 1 030 27 use the definition of momentum and kinetic energy to derive the relation

$$K = p^2/2m\ .$$

04 I 031 00	answer [illegible] verbal questions and solve problems pertaining to situations in which conservation of momentum is a significant factor.
04 I 031 01	use conservation of momentum to determine the speed [illegible] rowboat of known mass just after a man, al[illegible] of known mass, dives off the boat with a [illegible] horizontal component of velocity.
04 I 031 02	state that the total momentum of a system of particles remains constant *iff* the vector sum of the external forces acting on the system is zero; and (or) variation of this principle.
04 I 031 03	compute the speed of a freight car with certain initial speed after it collects a given amount of rain.

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04 I 031 21	relate Newton's third law of motion to conservation of momentum.
04 I 031 31	differentiate between internal and external forces of a system.

04 1 032 00	solve momentum problems involving bodies with variable mass.
04 1 032 01	choose from a list of equations the one which pertains to a rocket bolted on the launching pad, given the general equation for a rocket.
04 1 032 02	compute the time it takes a particular rocket to achieve its maximum speed, given the rate at which fuel is consumed.
04 1 032 03	determine the maximum upward speed of the rocket above, given the speed of the exhaust gases relative to the rocket.
04 1 032 04	select from a list of equations the one that applies to a "raindrop falling through a misty atmosphere."
04 1 032 05	use the equation $\vec{F} = \vec{v}\, dm/dt$ for a conveyor belt carrying sand at constant velocity to derive an expression for the cost in moving a total mass m, given the cost per unit energy.
04 1 032 06	derive an expression for the cost of moving a mass of sand m, if the conveyor belt starts from rest with all the sand on it rather than the sand fall on it at the rate dm/dt.

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04 1 032 22	recognize that a rocket achieves its maximum (upward) speed at the moment all the fuel is consumed.
04 1 032 24	recognize that the equation derived for a rocket applies to other situations in which the mass is varying.
04 1 032 25	recognize that what we are paying for is total energy used and <u>not</u> the rate at which energy is used up; i.e., the power.

04 1 033 00 analyze situations which involve net impulsive forces acting on bodies of constant mass.

04 1 033 01 use the impulse momentum principle to find an expression for the impulse imparted to a particle of known mass if its initial and final velocities are given.

04 1 033 02 apply Newton"s third law of motion to show that the impulse imparted by a particle <u>1</u> to particle <u>2</u> ($\vec{J}_{21}$) is equal in magnitude and opposite in direction to the impulse imparted by particle <u>2</u> to particle <u>1</u> ($\vec{J}_{12}$).

04 1 033 03 determine the expression for the momentum of the center of mass of two particles after each particle is given an equal and opposite impulse by the other particle (internal forces), if the common initial velocity and the masses of the particles are given.

04 1 033 04 use the impulse-momentum principle to compute the final momentum of a body of given initial momentum, after a given impulse is imparted to the body.

04 1 033 05 select from a list of statements the one that gives the reason a hammer is more effective than a human thumb in driving a thumb back into a piece of hard wood.

* * *

04 1 033 21 state the impulse-momentum principle.

04 1 033 24 recognize that impulse is a vector and must be treated as such.

04 2 034 00 use analytical methods to solve problems based on the definition of impulse,

$$\vec{J}_{12} = \int_1^2 \vec{F}\, dt .$$

04 2 034 01 find the magnitude of the impulse imparted to a block by a force which varies proportionately with time and is exerted to the block for a certain time period, T.

04 2 034 02 calculate the total time during which a given average force is acting if it imparts a given impulse to an object.

04 2 034 03 compute the work done to a body by an impulsive force, given the magnitude of the impulse imparted to the body by the impulse.

04 2 034 04 use the definition of impulse and the impulse momentum principle to solve various problems in kinematics.

04 2 035 00 use graphical methods to solve problems based on the definition of impulse

$$\vec{J}_{12} = \int_{1}^{2} \vec{F}\, dt \, .$$

04 2 035 01 calculate the magnitude of an impulse imparted to an object by computing the area under the force versus time curve.

04 2 036 00 answer verbal questions and analyze situations dealing with two-body collisions.

04 2 036 01 use Newton's third law of motion to conclude that in a collision between two bodies the mutual forces exerted by the bodies on each other are equal in magnitude and opposite in direction.

04 2 036 02 identify, from a given list of phenomena, those that constitute collisions between objects.

04 2 036 03 recognize that the net external force applied to a system being zero is a <u>necessary</u> and <u>sufficient</u> condition for conservation of momentum.

04 2 037 00	answer fundamental questions and solve problems pertaining to all one-dimensional non-relativistic collisions.
04 2 037 01	recognize that in inelastic collisions kinetic energy is not conserved; hence no "energy equation" can be written for such collisions.
04 2 037 02	relate the fact that in a collision between two bodies $\Delta\vec{p}_1 = -\Delta\vec{p}_2$ to Newton's third law of motion.
04 2 037 03	recognize that conservation of kinetic energy is what distinguishes an elastic collision from an inelastic one.
04 2 037 04	write the "momentum equation" applicable to any one-dimensional collision between two bodies.
04 2 037 05	solve problems on one-dimensional collisions which are neither perfectly elastic nor perfectly inelastic.
04 2 037 06	solve problems on one-dimensional collisions which are perfectly elastic.
04 2 037 07	solve problems on one-dimensional collisions which are perfectly (totally) inelastic.

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04 2 037 27	define a perfectly inelastic collision as one in which the two colliding particles stick together after the collision.

04 3 038 00	answer fundamental questions and solve problems involving two-dimensional collisions.
04 3 038 01	solve problems involving two-dimensional, perfectly inelastic collisions.
04 3 038 02	solve problems involving two-dimensional, perfectly elastic collisions.
04 3 038 03	solve problems involving two-dimensional collisions which are neither perfectly elastic nor perfectly inelastic.

05 1 039 00	answer fundamental questions relating to early attempts to understand the solar system.
05 1 039 01	recognize that Kepler formulated his laws of planetary motion based on observational data compiled by Tycho Brahe.
05 1 039 02	select from a list of verbal statements the one that best represents Kepler's first law of planetary motion.
05 1 039 03	use Kepler's third law of planetary motion to determine the relationship between one Pluto year and one earth year, given the mean radii of the two planets' orbits about the sun.

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05 1 039 22	state each of Kepler's three laws of planetary motion.

05 1 040 00	analyze verbal and mathematical statements relating to Newton's law of universal gravitation.
05 1 040 01	recognize that Newton's law of universal gravitation <u>does not</u> answer the question: "Why do bodies attract each other?"
05 1 040 02	recognize that the universal gravitational constant, G, must be determined experimentally; it cannot be computed from theory.
05 1 040 03	recognize that Newton's law of universal gravitation <u>does not</u> imply that the force of gravitational attraction between two bodies is independent of the shape of the bodies; in fact Newton formulated his law in terms of point particles.
05 1 040 04	recognize that the constant of universal gravitation, G, is just that -- a universal constant; its value is the same everywhere in the universe.

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05 1 040 21	recognize that a major accomplishment of Newton's law of universal gravitation was the derivation of Kepler's (empirical) laws of planetary motion.
05 1 040 31	recognize that a second major accomplishment of Newton's law was the synthesis of terrestrial and celestial mechanics into a single theory.

05 1 041 00	solve problems based on Newton's law of universal gravitation.
05 1 041 01	compute the radius of Phobos' (Mars' satellite) orbit about Mars, given the value of $\underline{g}$ on Mars, Mars' radius and the period of Phobos.
05 1 041 02	calculate the mass of Mars from various data on Mars and its satellite Phobos.
05 1 041 03	calculate the gravitational force exerted of the electron revolving about the proton in the Bohr picture of the hydrogen atom.
05 1 041 04	calculate the value of $\underline{g}$ on the surface of the moon, given the moon's radius and mass.

* * *

05 1 041 21	derive the relationship $a \propto 1/r^2$, for the acceleration of a body resulting from the gravitational force, using Newton's law of universal gravitation and his second law of motion.

05 1 042 00 answer fundamental questions and solve problems related to the variation of the value of g.

05 1 042 01 recognize that the period of a simple pendulum, measured with a spring chronometer, depends on the point of the "universe" at which the period is measured.

05 1 042 02 state that the value of g decreases as the distance from the center of the earth increases.

05 1 042 03 compute the weight of a body of known mass at a given altitude above the surface of the earth.

05 1 042 04 compute the difference in the weight of a mass of known mass between a point on the equator and a point on either pole of the (assumed spherical) earth.

05 1 042 05 compute the difference in the weight of a mass of known mass between a point on the equator and a point on the surface of the earth of given latitude.

05 1 042 06 recognize that a lever balance measures the mass of an object; hence, the "weight" of a man would be the same at a point on the equator and a point on either pole if the "weighing" is done with a lever balance.

* * *

05 1 042 22 derive an expression of the period of a simple pendulum and show that it depends on the value of g at the point the pendulum is located.

05 1 042 24 recognize that part of the difference in the value of g between the equator and the poles is due to the earth's rotation about its axis.

05 1 042 31 derive an expression for the period of oscillations of a mass-spring system and show that it is independent on the value of g.

05 1 043 00 answer fundamental questions relating to the concepts of inertial and gravitational mass.

05 1 043 01 select from a list of equations involving the mass of the bodies involved those equations in which m stands for gravitational mass.

05 1 043 02 derive an expression that would give g on the surface of the earth if the gravitational and the inertial masses were different.

05 1 043 03 name various experiments or laws that can be used to demonstrate that gravitational mass is conceptually different than inertial mass.

05 1 044 00 answer fundamental questions and solve problems pertaining to the application of Newton's law of universal gravitation to spherically symmetric bodies.

05 1 044 01 recognize that Newton's law of universal gravitation, although introduced for point particles, also applies for spherical bodies with spherical symmetry.

05 1 044 02 calculate the gravitational force on a particle inside a uniform spherical shell, when a second particle is located outside the shell.

05 1 044 03 calculate the gravitational force on a particle outside a uniform spherical shell, when a second particle is located inside the shell.

* * *

05 1 044 21 recognize that the density of a spherically symmetric body <u>is not</u> necessarily uniform but <u>it is</u> a function of the distance, r, from a point in the body (the center).

05 1 044 22 recognize that the gravitational force on a body inside a uniform spherical shell, due to the shell itself, is zero.

05 1 044 23 calculate the force exerted by a uniform spherical shell on a particle located outside the shell by considering all the mass of the shell as concentrated at its center.

05 1 044 32 recognize that a spherical shell separating two particles <u>cannot</u> act as a shield to the mutual gravitational force experienced by these particles.

05 2 045 00 answer fundamental questions and solve problems based on the motion of planets and satellites.

05 2 045 01 locate the center of mass of the earth-moon system.

05 2 045 02 calculate the altitude of an earth's satellite in circular orbit, if the satellite is to remain directly above a certain point of the earth's equator.

05 2 045 03 derive the relations $K = -U/2$, $E = U/2$ for a satellite in circular orbit about the earth.

05 2 045 04 calculate the final altitude of a satellite around the earth if it does certain amount of work against air resistance, given its initial altitude (circular orbit).

05 2 045 05 find the speed of a satellite given the radius of its orbit about the earth.

05 2 046 00 answer fundamental questions and solve problems based on the concept of the gravitational field (strength).

05 2 046 01 compute the magnitude of the gravitational field (strength) on the surface of Saturn.

05 2 046 02 compute the apparant weight of a known mass on the surface of Saturn.

05 2 046 03 locate the point between the earth and the moon at which the gravitational field of the earth-moon system is zero.

05 2 046 04 derive an expression for the magnitude of the gravitational field produced by a uniform spherical shell as a function of the distance of the field point from the center of the shell.

05 2 046 05 derive an expression for the magnitude of the gravitational field strength produced by a uniform sphere as a function of the distance of the field point from the center of the sphere.

* * *

05 2 046 21 define the gravitational field strength; i.e.,

$$\vec{\gamma} = -G \frac{M}{r^2} \hat{r} .$$

05 2 046 22 define apparent weight as

$$W_a = mg = m(\gamma - a_c)$$

where a_c is the component of the centripetal acceleration along the radius vector.

05 2 046 23 recognize that the gravitational field (strength) is a vector quantity.

05 2 047 00	answer fundamental questions and solve problems based on the concept of gravitational potential.
05 2 047 01	relate gravitational potential to gravitational field.
05 2 047 02	derive an expression for the magnitude of the gravitational potential produced by a uniform spherical shell as a function of the distance of the field point from the center of the shell.
05 2 047 03	derive an expression for the magnitude of the gravitational potential produced by a uniform sphere as a function of the distance of the field point from the center of the sphere.
05 2 047 04	calculate the gravitational potential at that point between the earth and the moon at which the gravitational field is zero.
05 2 047 05	state that the fact that at the point mentioned above $\gamma = 0$ whereas $V \neq 0$ (or $U \neq 0$) does not contradict the idea of choosing the reference point for $V = U = 0$ where $\gamma = F = 0$.

05 2 048 00 answer fundamental questions and solve problems related with the concept of gravitational potential energy.

05 2 048 01 state that the potential energy of a mass m placed a distance r from the center of the earth is equal to the negative of the work done by the gravitational force in bringing the point from a point at infinity to the point in question.

05 2 048 02 state that the choice of the earth's surface as the zero gravitational potential reference is good only for terrestrial mechanic, where the contributions of other celestial bodies can be neglected.

05 2 048 03 state that the expression $U = mgy$, for the potential energy of a mass m at an altitude y, is good only near the surface of the earth with the earth's surface taken as the zero potential energy reference.

05 2 048 04 give as a judicious choice for the point at which the potential energy of a system (not necessarily gravitational) is zero the point at which the force on the system is also zero.

05 2 048 05 use conservation of mechanical energy to compute the speeds of two spheres when they collide if the spheres have started from rest on a frictionless table, given their initial separation.

05 2 048 06 use conservation of mechanical energy to find to what separation the two spheres above rebound if a given part of their energy is lost during their collision.

05 2 048 07 use conservation of energy to solve problems dealing with escape velocity (speed).

05 2 048 08 find the maximum altitude that a body attains, given the upward speed with which the body leaves the earth's surface.

05 2 048 09 compute the work done against gravity in assembling a number of particles starting with the particles at infinity, and recognize that this work is equal to the total potential energy of the assembly.

06 1 049 00	apply Coulomb's law.
06 1 049 01	define charge as the origin of electrical force.
06 1 049 02	recognize that the electron contains the most elementary unit of charge.
06 1 049 03	define quantization as a fixed amount of a physical property.
06 1 049 04	recognize that resinous charge is synonymous with negative charge.
06 1 049 05	recall that the constant in Coulomb's law $(1/4\pi\varepsilon_o)$ is 9×10^9 N-m^2/C^2.
06 1 049 06	recall that the most elementary quantity of charge is 1.6×10^{-19} coulombs.
06 1 049 07	recall that although Coulomb's law holds only for point charges it can be extended to larger objects by considering differential elements of charge.

06 1 050 00	demonstrate the nature of charges produced by rubbing insulators.
06 1 050 01	define an ideal insulator as a material in which charges are fixed at all times.
06 1 050 02	recognize that positive and negative charges stem from triboelectrifying glass and rubber rods.
06 1 050 03	recall that positive charge is produced by rubbing an insulated glass rod with a silk cloth.

06 1 051 00	recall the fact the quantity of charge in a closed system does not change.
06 1 051 01	define a coulomb of charge as the amount of charge that flows through a given cross section of wire in one second if there is a steady current of one ampere in the wire.

06 1 052 00 use the concept of electric field to calculate force on charges located in the field.

06 1 052 01 recall that Newton's second law for a charged particle in an electric field is

$$q\vec{E} = m\vec{a} \ .$$

06 1 052 02 recall that the force on a charge in an electric field is

$$\vec{F} = q\vec{E} \ .$$

06 1 052 03 recognize that charged particles do not influence each other directly and that the electric field is a go-between.

06 1 053 00	calculate the electric field for any distribution of charge.
06 1 053 01	define electric field strength as the force per unit charge acting on a charge placed in the field.
06 1 053 02	recognize that the direction of the electric field is chosen to be the direction in which a positive charge would tend to move if placed in the field.
06 1 053 03	recognize that electric field is a vector and must be added or subtracted as a vector.
06 1 053 04	recall that the electric field has a unique value at every point in space surrounding a charge particle.
06 1 053 05	recall the value of the electric field near an infinitely large plane that is uniformily charged.

06 1 054 00	use an electroscope to determine qualitative and quantitative aspects of charge.
06 1 054 01	recognize that two positive charges repel each other.
06 1 054 02	recognize that two negative charges repel each other.
06 1 054 03	recall that unlike charges attract.

06 1 055 00	draw the electric lines of force due to symmetric charge distributions.
06 1 055 01	recall that lines of force are directed away from an isolated positive charge.
06 1 055 02	recognize that the density of the lines of force is directly proportional to the electric field strength.
06 1 055 03	recall that lines of force are directed toward an isolated negative charge.
06 1 055 04	recognize that the tangent to a line of force at any point gives the direction of E at that point.

07 1 056 00	calculate the forces on an electric dipole in an electric field.
07 1 056 01	define the direction of a dipole by an imaginary vector drawn from the negative to the positive charge forming the dipole.
07 1 056 02	recognize that the net force acting on a dipole in an electric field is zero.
07 1 056 03	recognize that an electric dipole consists of two charges of opposite sign separated by a fixed distance.
07 1 056 04	recall that the direction of the dipole moment is from the minus charge to the plus charge.

07 1 057 00 apply the concept of torque to situations of a force acting at a distance from the center of mass of a system.

07 1 057 01 define the torque vector by:

$$\vec{\tau} = \vec{r} \times \vec{F} .$$

07 1 057 02 recognize the spatial significance of the force, displacement and torque vectors.

07 1 058 00 calculate the net torque acting on a dipole in an electric field.

07 1 058 01 recall that the position of a dipole in an electric field determines the net torque.

07 1 058 02 recall that the net torque on a dipole is zero if the dipole axis is aligned with the field.

07 1 058 03 recall that the magnitude of the torque on a dipole is given by

$$\tau = 2\ qEa\ \sin\theta\ .$$

07 1 058 04 recall that the magnitude of the torque in terms of the dipole moment is

$$\tau = E\ p\ \sin\theta\ .$$

07 1 058 05 define a dipole moment by the expression $p = 2qa$ where q is the electric charge and $\underline{a}$ is the distance between charges.

07 1 058 06 define the torque on a dipole by

$$\vec{\tau} = \vec{p} \times \vec{E}.$$

07 1 058 07 calculate the dipole moment from its charge and separation distance.

07 1 058 08 define the torque on a dipole as the derivative of the work with respect to the angular displacement,

$$\tau = \frac{dW}{d\theta}\ .$$

07 1 058 09 recall that for distant points along the dipole axis, the electric field varies as the inverse of the distance cubed.

07 1 059 00 calculate the energy stored in an electric dipole in an electric field.

07 1 059 01 recall that work done on or by an electric field can be either positive or negative.

07 1 059 02 recall that the expression for work done by a torque acting through an angular displacement is

$$dW = \tau \, d\theta \, .$$

07 1 059 03 recall that the maximum potential energy orientation of a dipole occurs when the dipole moment is 180 degrees to the electric field.

07 1 059 04 write the expression for the potential energy of a dipole as

$$U = -\vec{p} \cdot \vec{E} \, .$$

07 2 060 00 calculate the electric field at a point by superposition of electric fields from individual charge distributions.

07 2 060 01 recall that the electric field due to a large, uniformily charged plate is $\sigma/2\varepsilon_0$.

07 2 060 02 recall that two electric field vectors can be added at a point regardless of the shape of the charge distributions causing the two fields.

07 2 061 00	calculate the trajectory of a charged particle travelling in an electric field.
07 2 061 01	determine the expression for the vertical deflection of a charged particle projected horizontally at right angles to a uniform electric field.
07 2 061 02	recognize that a constant electric field produces constant acceleration of charged particles.
07 2 061 03	recall that the velocity of a charged particle parallel to two parallel plates will be constant.

07 2 062 00 calculate the work required to move a charge between two points in a constant electric field.

07 2 062 01 recall that electric forces are conservative.

07 2 062 02 relate the work done on a charged particle moved in an electric field to its kinetic energy.

07 2 062 03 recall that work in an electric field is

$$W = \int \vec{E}q \cdot d\vec{s}.$$

07 2 062 04 recall that the work done around a closed path in an electric field is zero.

07 2 063 00 calculate the work required to move a charged particle between two points in a variable electric field.

07 2 063 01 recall that for a point charge being moved in the direction of the field of another point charge, the work by an outside agent is calculated by

$$W = -\int \frac{q_1 q_2}{4\pi\varepsilon_o r^2}\, dr \ .$$

07 2 063 02 recall that for a point charge being moved in the opposite direction of the field near an infinitely long, positively charged wire, the work done on the charge is

$$W = -\int \frac{\lambda\ q}{2\pi\varepsilon_o r}\, dr \ .$$

09 1 064 00	define electric flux through any surface.
09 1 064 01	recall that electric flux is a measure of the lines of force that cut through an arbitrarily specified, hypothetical surface.
09 1 064 02	define the vector direction of a surface as the direction of a vector perpendicular to a surface.
09 1 064 03	recall that electric flux can be approximated by $$\phi = \Sigma\vec{E}\cdot\Delta\vec{s}\ .$$
09 1 064 04	recognize the analogy between fluid flow and flux.
09 1 064 05	recall that flux (symbol ϕ) is a property of any vector field.

09 1 065 00	calculate the electric flux through any surface.
09 1 065 01	calculate the electric flux through a surface parallel or perpendicular to the electric field.
09 1 065 02	calculate the electric flux through a surface at an acute angle to the electric field.
09 1 065 03	calculate the electric flux through a surface part of which is parallel and part of which is perpendicular to the electric field.
09 1 065 04	calculate the electric flux through a half cylindrical shell.
09 1 065 05	calculate the flux of fluid through a pipe.
09 1 065 06	calculate the flux through a hemispherical shell whose flat surface is perpendicular to the electric field.
09 1 065 07	calculate the flux through a hemispherical shell whose flat surface is parallel to the electric field.
09 1 065 08	recall that the magnitude and direction of the field vector must be known at every point on the surface in order to calculate the flux.

09 1 066 00	recognize that the electric flux through any closed surface is zero in the absence of a source within the closed surface.
09 1 066 01	recall that flux is a scalar and may be added algebraically.
09 1 066 02	define electric flux as positive when, for a closed surface, the lines of force point everywhere outward.

09 2 067 00 apply Gauss's law.

09 2 067 01 recognize that a positive charge acts as a source of flux and a negative charge acts as a sink of electric flux.

09 2 067 02 recognize that a negative line of charge with a closed cylindrical surface acts as a sink of electrical flux.

09 2 067 03 recall that the net flux through a closed surface can be found from

$$\phi_E = \Sigma\phi_+ - \Sigma\phi_-$$

where ϕ_+ is the flux due to the positive charges and ϕ_- is the flux due to the negative charges within the closed surface.

09 2 067 04 recall that Gauss's law states that the electric flux through any closed surface is directly related to the algebraic sum of the charges enclosed.

09 2 067 05 recall that a Gaussian surface is best defined as any closed surface, whether or not there is a charge present.

09 2 067 06 recognize that the general form of Gauss's law is

$$\oint \vec{E}\cdot d\vec{S} = \frac{q}{\varepsilon_o} .$$

09 2 067 07 recognize that the q term in Gauss's law indicates the net charge enclosed by the Gaussian surface.

09 2 067 08 recall that the electric flux through any closed surface is independent of the location of charges within the volume enclosed by the surface.

09 2 067 09 recall that for a charged, insulated conductor in electrostatic equilibrium, the electric field is zero everywhere inside the conductor.

09 2 068 00	Demonstrate the use of Gauss's law to determine the value of the electric field at a point.
09 2 068 01	recall that Gauss's law car .e used to determine the value of the electric iield at a point.
09 2 068 02	recognize that the most convenient Gaussian surface to determine the electric field around a point charge is a spherical surface.
09 2 068 03	recognize that the electric field outside of a charged spherical conductor decreases as one over the radius squared.
09 2 068 04	recall that for a spherical Gaussian surface surrounding a point charge at its center, E is constant everywhere on its surface.
09 2 068 05	recognize that the electric field outside of a charged, spherical non-conductor decreases as one over the radius squared.
09 2 068 06	use Gauss's law to demonstrate that the field inside a uniformly charged non-conducting sphere can be found by $$E = \frac{\rho r}{3\ \varepsilon_o}.$$
09 2 068 07	recognize that the electric field inside of a charged spherical shell is zero.
09 2 068 08	describe the Thompson atom as a sphere of radius 10^{-10} m with the positive charge distributed throughout the atom.
09 2 068 09	describe the Rutherford atom as a sphere of radius 10^{-15} m with the positive charge concentrated in the nucleus.

09 2 069 00	use Gauss's law to determine the distribution of charges in a conductor.
09 2 069 01	recognize that the charge from a previously charged metal ball touched to the inside surface of a conducting can will reside on the outside surface of the can.
09 2 069 02	recognize that a pith ball introduced into a charged conducting pail will have no electric forces acting upon it.
09 2 069 03	define the symbol ρ (rho) as the charge per unit volume.
09 2 069 04	define a uniform, spherical charge distribution as one in which the charge density ρ is independent of the orientation or distance from the center of the sphere.
09 2 069 05	recall that the symbol λ (lambda) is used to represent the linear charge density.
09 2 069 06	recall that the surface charge density on a conductor may vary from point to point depending on the shape of the surface of the conductor.
09 2 069 07	demonstrate that excess electric charge resides on the surface of a conductor.

09 3 070 00	demonstrate graphically the variation of the electric field with distance from a charge distribution.
09 3 070 01	recognize the variation of the electric field with distance from a charged conducting sphere.
09 3 070 02	recognize the variation of the electric field with distance from a uniformly charged, non-conducting cylinder.
09 3 070 03	recognize the variation of the electric field with distance from two concentric, equally charged spheres.
09 3 070 04	recognize the variation of the electric field with distance from a hollow, charged, conducting cylinder.
09 3 070 05	recognize the variation of the electric field with distance from a uniformly charged, non-conducting sphere.

10 1 071 00 define electric potential difference between two points, A and B, as the work per unit charge that must be done to move a positive test charge from A to B, always keeping the charge in equilibrium.

10 1 071 01 recall that the electric potential is determined between points A and B by the equation,

$$V_B - V_A = \frac{W_{AB}}{q_o} .$$

10 1 071 02 recognize that the work term appearing in (01) may be positive, negative or zero.

10 1 071 03 define electric potential at a point as the potential difference between the point and infinity, infinity taken as the zero reference.

10 1 071 04 recognize that the work W_{AB} and consequently the potential difference $V_B - V_A$ appearing in (01) to be path independent.

10 1 072 00	answer questions and solve problems dealing with the electric potential due to a point charge.
10 1 072 01	calculate the electric potential due to a point charge.
10 1 072 02	identify the volt as a joule per coulomb.
10 1 072 03	recognize that the equipotential surfaces of a point charge are concentric spheres.
10 1 072 04	calculate the charge which produces a given value of electric potential at a specific point in space.

10 1 073 00	answer questions and solve problems dealing with the electric potential due to a system of point charges.
10 1 073 01	calculate the electric potential due to a system of two or more point charges.
10 1 073 02	derive the potential due to a dipole at a distance far away from it.
10 1 073 03	calculate Ey when the potential due to a dipole is given.
10 1 073 04	recognize that the amount of work one has to do in bringing a test charge to a distance x from a dipole along the perpendicular bisector of the dipole axis is zero.
10 2 073 05	derive the electric potential due to a quadrupole at distance r on its axis.
10 2 073 06	calculate the electric field intensity E at a distance r from the quadrupole on its axis.

10 1 074 00	answer questions and solve problems dealing with the electric potential due to a continuous charge distribution.
10 1 074 01	calculate the electric potential due to a continuous, line, charge distribution.
10 1 074 02	calculate the electric potential in the region between two infinite, conducting, charged sheets.
10 1 074 03	calculate the distance between equipotential surfaces whose potentials differ by the given voltage in the region between two infinite conducting, charged sheets.
10 1 074 04	calculate the electric potential due to a uniformly charged ring.

10 1 075 00 solve problems and answer questions on the relationship between electric potential and electric field intensity.

10 1 075 01 recognize that the electric field in the direction of ℓ is derivable from the electric potential by the relation

$$E_{\ell} = - \frac{dV}{d\ell} .$$

10 1 075 02 calculate the electric field intensity at a point along a given direction when the electric potential is given as a function of distance.

10 1 075 03 identify graphically the relationship between electric potential and electric field intensity.

10 2 076 00 answer questions and solve problems concerning electric potential energy.

10 2 076 01 specify that the electric potential energy of a charge distribution represents the work to establish a specific charge distribution.

10 2 076 02 determine the electric potential for a system of more than two charges by computing the electric potential energy for each additional charge separately and adding results algebraically.

10 2 077 00 answer questions and solve numerical problems involving the physical significance of electric capacitance.

10 2 077 01 recognize that the capacitance of two equally charged conductors separated by a non-conductor is defined as the ratio of the charge on either conductor to the electric potential difference between them, $C = Q/V$.

10 2 077 02 show from the definition of capacitance that the unit of capacitance is the farad (F), which is a coulomb per volt.

10 2 077 03 calculate the charge on a plate of a capacitor when its capacitance and the potential difference across its terminals are given.

10 2 078 00 answer questions and solve problems involving the capacitance of a parallel-plate capacitor having two plates each of area A, separated by a distance d in vacuum.

10 2 078 01 write the expression $E = q/A\varepsilon_o$ for the electric intensity between two equally charged plates (opposite sign) in a vacuum.

10 2 078 02 recall that the electric potential difference of a pair of equally charged parallel conducting plates is given by

$$V = Ed \;.$$

10 2 078 03 write that since $C = Q/V$ the expression for capacitance for two equally charged plates becomes

$$C = \frac{\varepsilon_o A}{d} \;.$$

10 2 078 04 calculate the capacitance of a parallel plate capacitor when the area of the plate and the separation between two plates are given.

10 2 079 00	solve problems involving capacitors with various conductor-pair geometries and the corresponding capacitance.
10 2 079 01	calculate capacitance of a capacitor consisting of two concentric, conducting, hollow spheres with radii r and R, respectively.
10 2 079 02	calculate the capacitance of the earth, viewed as an isolated conducting sphere with a radius of 6400 km.
10 2 079 03	calculate the capacitance of a capacitor formed by two concentric hollow cylinders with length ℓ, having radii <u>a</u> and <u>b</u>, respectively.

11 1 080 00 solve descriptive and numerical problems involving capacitors in series and parallel combinations. (Note: All interconnecting wires are resistanceless.)

11 1 080 01 define the equivalent capacitance of a combination of capacitors as that capacitance which could replace the original combination in any electrical circuit without changing circuit operation.

11 1 080 02 recognize that the potential difference across any capacitor in a parallel combination is the same as that across every other capacitor in the combination.

11 1 080 03 calculate the equivalent capacitance of a number of capacitors all connected in parallel.

11 1 080 04 recognize that the sum of the potential differences across a group of capacitors in series is equal to the potential difference across the combination.

11 1 080 05 recognize that the charge stored by a series combination of capacitors is less than that charge that would be stored by any of the elements of the combination if the same potential were applied across it.

* * *

11 1 080 23 derive the equation which shows that the equivalent capacitance of any number of capacitors in parallel is the sum of the individual capacitances.

11 1 080 25 derive the equation giving the equivalent capacitance of any number of capacitors in series as

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots + \frac{1}{C}.$$

11 1 080 35 state that the equivalent series capacitance is always smaller than the smallest capacitance in the group.

11 1 081 00 show the steps in deriving the capacitor energy equation

$$U = \frac{1}{2} CV^2$$

where U is the electrical energy stored in the electric field, C is the capacitance, and V is the potential difference across the plates.

11 1 081 01 state that any charge configuration has an electric potential energy U equal to the work W required to assemble the configuration from its components originally taken as infinitely far apart and at rest.

11 1 081 02 state that, if a charge q is moved from one plate to the other of an initially uncharged capacitor, the potential difference across the capacitor will be

$$V = q_o/C .$$

11 1 081 03 state that, if an additional increment of charge dq is moved from one plate to the other of a capacitor across which a potential difference $V = q_o/C$ already exists, the work increment will be

$$dw = (q_o/C)\ dq .$$

11 1 081 04 recognize that, if in a capacitor the charging process is carried out until a charge Q has been transferred from one plate to the other, the total work done is given by

$$W = \int_o^Q (q/C)\ dq .$$

11 1 081 05 integrate the expression

$$W = \int_o^Q (q/C)\ dq .$$

to obtain

$$W = \frac{1}{2}\frac{Q^2}{C} .$$

11 1 081 06 use the relation Q = CV to change

$$W = (1/2)\ (Q^2/C)$$

to the form

$$W = (1/2)\ CV^2\ .$$

11 1 081 07 recognize that the work done in charging a capacitor ($W = (1/2)\ Q^2/C = (1/2)\ CV^2$) is stored in the capacitor as electrical energy.

11 1 082 00	analyze fully any capacitative circuit; that is determine the equivalent capacitance, the charge in each capacitor, the potential difference across each capacitor and the energy stored in each capacitor.
11 1 082 01	determine the equivalent capacitance of a circuit consisting of capacitors connected in series and in parallel.
11 1 082 02	determine the total charge supplied by a battery to a circuit of capacitor whose equivalent capacitance has been computed.
11 1 082 03	determine the charge stored in each of the capacitors in a capacitative circuit knowing the total charge supplied by the battery.
11 1 082 04	determine the potential difference across each of the capacitor in the circuit of the foregoing problem.
11 1 082 05	determine the energy stored in each of the capacitors of the above circuit.
11 1 082 06	analyze the situation in which the battery is removed from the above circuit and a new capacitor connected in its place. In particular find the charge in the new capacitor.

11 1 083 00 predict the effect of adding a dielectric of known dimensions and material to a vacuum capacitor in both descriptive and quantitative situations.

11 1 083 01 state that when dielectric is placed between the plates of a charged capacitor it is pulled into the gap by attractive forces.

11 1 083 02 select from a list of alternatives the characteristics of a dielectric.

11 1 083 03 recognize that when a dielectric is inserted into an isolated charged capacitor, the potential difference across the capacitor drops.

11 1 083 04 write the capacitance equation for a parallel-plate capacitor with a dielectric of constant K as

$$C = \frac{KE_0A}{d}$$

in which E = permittivity constant of free space,
A = plate area, and
d = plate separation.

11 1 083 05 calculate the capacitance of a capacitor of known air capacitance when the capacitor is immersed in oil of given dielectric constant.

11 1 083 06 calculate the ratio of potential differences across two identical capacitors given identical charges if one of them is filled with a dielectric of known K.

11 1 083 07 state that the induced surface charge on a dielectric tends to decrease the electric field between the plates of a capacitor by a factor of K.

* * *

11 1 083 23 indicate that, when two capacitors of identical dimensions, one using a vacuum and the other a material dielectric of dielectric constant K, are given the same charge, then V = V /K where V is the potential difference across the capacitor with dielectric and V is the potential difference across the vacuum capacitor.

11.1 083 24 define the dielectric constant K of a material as the ratio $K = C_d/C_o$, where C_d = capacitance with dielectric and C_o = capacitance without dielectric.

11 2 084 00 discuss the nature of the electric current and the units used to measure it.

11 2 084 01 recall that electrons are in random motion in an isolated metallic conductor so that the net directed motion in any direction is zero.

11 2 084 02 recall that the electrons in an isolated metallic conductor placed in an electric field rearrange themselves to produce a field-free region in the interior of the conductor.

11 2 084 03 state that any excess charge on a conductor, regardless of its sign, will distribute itself uniformly throughout the surface of the conductor.

11 2 084 04 state that a continuous current will be present in a metallic conductor if a continuous field or potential gradient can be maintained within it.

11 2 084 05 recognize that a battery or chemical cell can produce such a continuous field or potential gradient in a metallic conductor when properly connected to it.

11 2 084 06 give the direction of motion of electrons in a metallic conductor as being opposite to the direction of the electric field within it (or the potential gradient).

11 2 084 07 state that the magnitude of the electric current is equivalent to the rate of transfer of charges past a given point in the conductor or $i = dq/dt$ where i = current, dq/dt = rate of transfer of charge.

11 2 084 08 recognize that one ampere of current is the equivalent of one coulomb of charge per second passing a given point in a conductor.

11 2 084 09 define current density (j) as $j = i/A$ where A is the cross-sectional area of the conductor in which the current is uniformly distributed.

11 2 084 10 solve a problem in which the current density in a wire of known diameter is to be determined given the value of the steady current through it.

11 2 085 00 define and use resistivity and resistance in the solution of verbal and numerical problems involving simple electric circuits.

11 2 085 01 define the resistance (R) of a specific conductor as the ratio of the potential difference (V) applied across two points on it and the current (i) which then appears in it; that is, $R = V/i$.

11 2 085 02 define the resistivity (ρ) of a conducting material as the ratio of the electric intensity (E) and the current density (j) or $\rho = E/j$, provided that the material is electrically isotropic.

11 2 085 03 derive, using $E = V/\ell$ and $j = i/A$, the relationship $R = \rho\ (\ell/A)$ where ℓ = length of conductor and A = cross-sectional area of conductor.

11 2 086 00	apply Ohm's law to the solution of problems for which this law is suited. (That is, for conductors whose resistance is independent of voltage or current).
11 2 086 01	define a linear conductor or circuit as one in which the resistance is independent of voltage or current.
11 2 086 02	recognize that $R = V/i$ consistently defines resistance whether the conductor is linear or non-linear.
11 2 086 03	determine the voltage applied across a linear circuit given data which permits the calculation of resistance and current.
11 2 086 04	determine the current in a linear circuit given the voltage and resistance.

12 1 087 00	describe the action and function of a source of emf in a simple electric circuit.
12 1 087 01	define a source of emf as a device that is capable of maintaining a potential difference between two points to which it is attached.
12 1 087 02	list a dry cell, a storage battery, and a generator (dynamo) as common seats of emf.
12 1 087 03	state that the emf ε of a seat may be defined from $\varepsilon = dW/dq$ where dW is the work done by the seat on a charge dq.
12 1 087 04	identify the types of energy transfers and the device which makes each conversions.
12 1 087 05	recall that an emf is a device in which the energy transfer is theoretically reversible.

12 1 088 00 recall Joule's law: in an electric circuit containing linear elements (R independent of i), the rate of development of heat (H) is directly proportional to the square of the current or

$$\frac{dH}{dt} = i^2R.$$

12 1 088 01 recall that the amount of energy transformed in moving a charge from a to b is given by $dU = dq\ V_{ab}$ in which dq is the transferred charge and V_{ab} is the potential difference between a and b.

12 1 088 02 recognize that power, time-rate of energy transfer, is described by $\frac{dU}{dt} = i\ V_{ab}$.

12 1 088 03 recall that for a resistor $R = \frac{V}{i}$ and therefore that the rate of heat production may be written

$$P = \frac{dH}{dt} = \frac{dU}{dt} = i^2R \quad \text{which is Joule's law.}$$

12 1 088 04 recogni that Joule's law applies only to resistors and may be ten in any one of three ways:

$$P = i^2r$$

$$P = \frac{v^2}{R}$$

$$P = iV \ .$$

12 1 089 00 solve typical problems involing Joule's law.

12 1 089 01 solve problens in which the current and rate of heating in a resistor are given to find the resistance.

12 1 089 02 solve a problem in which are given
(a) the voltage across a wire
(b) the length, gauge and material of the wire to find the rate of Joule heating.

12 1 089 03 solve a problem in which are given
(a) the rated power dissipation of a resistor at a given voltage
(b) a new voltage to which the emf drops in order to find the percentage drop in heat output at the new voltage assuming constant R.

12 2 090 00 calculate the current in single loop resistive circuits, given the required circuit constants.

12 2 090 01 recall the expression relating circuit current to emf and resistance, i.e., $i = \varepsilon/R$.

12 2 090 02 recognize that a specific point in a single loop circuit can have only one potential at at any time with respect to a given reference.

12 2 090 03 state that the algebraic sum of the changes in potential encountered in going once around a single loop circuit must be zero.

12 2 090 04 write the loop equation including the internal resistance of the seat of emf, i.e., $\varepsilon - ir - iR = 0$, where r=internal resistance.

12 2 090 05 solve a numerical problem involving a single-loop, single resistor circuit for which are given ε, i, and R to find r (internal resistance).

12 2 090 06 solve a numerical problem involving a single-loop, single resistor circuit for which are given i, r, and R to find ε.

12 2 090 07 state the sign conventions for voltage drops and emf's as follows:

1. the voltage drop is positive ($+iR$) if a resistor is traversed opposite to direction of conventional current: negative ($-iR$) if traversed in some direction.
2. the emf is positive ($+\varepsilon$) if the seat is traversed in the same direction as its emf: negative ($-\varepsilon$) if the seat is traversed in the opposite direction.

12 2 091 00	solve problems involving resistors in series, parallel, and series-parallel combinations when only one seat of emf is present in the circuit.
12 2 091 01	state that the potential difference across each resistor in a parallel circuit is the same.
12 2 091 02	state that the value of the current in each resistor of a series circuit is the same.
12 2 091 03	recognize that the currents in any two elements of a parallel circuit are inversely proportional to their resistances or $I_1/I_2 = R_2/R_1$.
12 2 091 04	recognize that the voltage drops across any two elements of a series circuit are directly proportional to their resistances or $V_1/V_2 = R_1/R_2$.
12 2 091 05	determine the equivalent resistance of a series circuit.
12 2 091 06	determine the total current in the seat of emf of a series-parallel circuit.
12 2 091 07	determine the voltage drop across each resistor of a series-parallel circuit.
12 2 091 08	determine the equivalent resistance of a parallel circuit.
12 2 091 09	determine the current in each resistor of a series-parallel circuit.

12 2 092 00 answer questions relative to the methods of application of Kirchhoff's rules to electric networks.

12 2 092 01 recognize that Kirchhoff's first rule implies that no charge can ever accumulate at a branch point; i.e., conservation of charge.

12 2 092 02 recognize that the direct basis for Kirchhoff's second rule is conservation of energy.

12 2 092 03 state that the sign convention to be used calls for assigning a plus (+) sign to a current which approaches a reference branch point and a minus (-) sign to a current which leaves the reference branch point.

12 2 092 04 identify the branch points and loops in a typical electrical network containing at least two seats of emf and at least three loops.

12 2 093 00 apply Kirchhoff's rules to the solution of numerical problems ranging from simple to more complex multiloop networks.

12 2 093 01 solve problems with numerical values assigned to all ε's and R's with the loop current being unknown.

12 2 093 02 solve multiloop problems with mumerical values assigned to all ε's an R's with the loop currents being unknown.

12 3 094 00	answer questions and solve problems relating to the construction and use of an ammeter in measuring electric current.
12 3 094 01	recall that an ideal ammeter would have zero resistance.
12 3 094 02	recognize that a shunt resistance is connected across the coil of an ammeter to modify the ammeter to read higher currents.
12 3 094 03	recognize that an ammeter must be connected in series with the portion of the circuit at which the current is to be measured.

12 3 095 00 answer questions and solve problems relating to the construction and use of meters for measuring potential difference.

12 3 095 01 recall that a voltmeter will generally consist of a galvanometer with a high resistance connected in series with the coil.

12 3 095 02 recognize that the potentiometer is a null instrument; i.e., it makes measurements by giving a zero reading.

12 3 096 00	answer questions and solve problems relating to the measurement of resistance by means of a Wheatstone bridge.
12 3 096 01	recognize that the Wheatstone bridge can be used to measure unknown resistances with great precision.
12 3 096 02	recall that for a Wheatstone bridge

$$R_V = \frac{R_2}{R_1} R_X \quad .$$

13 1 097 00 answer qualitative questions referring to the nature of a magnetic field.

13 1 097 01 state that a magnetic field is said to exist in a given region of space if a direction of motion of an electric charge through this region can be found such that the moving charge experiences a force over and above any electrostatic or gravitational forces.

* * *

13 1 097 21 state that a magnetic field must be described in terms of a vector quantity which gives its intensity and direction.

13 1 097 31 recognize that a magnetic field may be mapped graphically by means of lines of magnetic "force" in a manner similar to that used to map an electric field.

13 2 098 00 answer qualitative questions relating to the magnetic induction vector $\vec{B}$.

13 2 098 01 define the magnitude of the magnetic vector $\vec{B}$ through a given point in a magnetic field as

$$B = \frac{F_1}{q_o v}$$

where F_1 = magnitude of force acting on charge q_o moving at right angles through the field with velocity v.

* * *

13 2 098 21 state that the basic magnetic field vector $\vec{B}$ is variously known as the magnetic induction vector or the magnetic intensity vector.

13 2 098 31 indicate that lines of magnetic induction give a graphic representation of the way $\vec{B}$ varies throughout a given region of space.

13 2 098 41 state that the tangent to a line of induction gives the direction of $\vec{B}$ at that point.

13 2 098 51 recognize that lines of induction are drawn so that the number of lines per unit cross-sectional area is proportional to the magnitude of the vector $\vec{B}$.

13 2 098 61 define the direction of the magnetic vector $\vec{B}$ through a given point in a magnetic field as the <u>line</u> along which an electric charge may move through the point <u>without</u> experiencing a force.

13 1 099 00 answer definitive questions relating to magnetic flux ϕ_B, and exhibit complete familiarity with the various MKS units for $\vec{B}$ and ϕ_B.

13 1 099 01 define magnetic flux ϕ across a surface as the surface integral of the normal components of B over the surface or

$$\phi = \int \vec{B} \cdot d\vec{A} .$$

13 1 099 02 recognize that for the special case in which $\vec{B}$ is uniform and at an angle θ to a finite area, flux is given by $\phi = |\vec{B}|\ |\vec{A}|\ \cos(\theta)$.

13 1 100 00 solve numerical problems involving $\vec{B}$, ϕ_B, and related quantities such as force on a moving charge, magnitude of moving charge, and velocity of moving charge.

13 1 100 01 recall that the direction of the force on a moving charge in a magnetic field is perpendicular to a plane formed by the vectors $\vec{v}$ and $\vec{B}$.

13 1 100 02 recall that when a charged particle moves through a region in which both an electric field and a magnetic field are present, the resultant force is found by

$$F = q_o\vec{E} + q_o\vec{v} \times \vec{B} \quad .$$

13 2 100 03 recall that the force on a moving charge in a magnetic field is found from

$$\vec{F} = q_o\vec{v} \times \vec{B} \quad .$$

13 3 101 00	answer questions relative to the magnetic field of the earth.
13 3 101 01	recognize that the horizontal component of the earth's magnetic field is generally directed northward in both hemispheres.
13 3 101 02	recognize that the vertical component of the earth's magnetic field is generally directed downward in the northern hemisphere and upward in the southern hemisphere.
13 3 101 03	recall the horizontal and vertical variation of the earth's magnetic field as you travel from the magnetic equator to the magnetic poles.
13 3 101 04	define declination as the error in degrees from true north to which the magnetic compass points.
13 3 101 05	define inclination as the angle of a dipping magnetic needle below the horizontal.
13 3 101 06	calculate the eastward, northward, and vertical components of $\vec{B}$.

13 1 102 00 apply the fundamental equation for the force acting on a current-carrying conductor immersed in a magnetic field

$$\vec{F} = i\vec{\ell} \times \vec{B} .$$

13 1 102 01 recognize that the force on a current-carrying wire in a magnetic field is equal to $\vec{F} = i\ell B_{\perp}$ where $B_{\perp}$ is the component of $\vec{B}$ normal to the rod.

13 1 102 02 recall that the magnitude of the force on a current-carrying conductor in a magnetic field is independent of the area of the conductor.

13 1 102 03 apply the right-hand rule to find the direction of the force on a current-carrying conductor in a magnetic field.

13 1 102 04 recall that the force on a small element of wire is given by

$$d\vec{F} = i\,d\vec{\ell} \times \vec{B} .$$

13 1 102 05 solve for the force on a current-carrying conductor where the magnetic field is not perpendicular to the conductor.

13 1 102 06 solve for the force on a current-carrying conductor where the magnetic field is not constant in magnitude.

13 1 103 00 apply the equation for the torque on a current-carrying loop in a magnetic field.

13 1 103 01 recall that the magnitude of the torque on a current-carrying loop is

$$\tau = iSB \sin\theta \ .$$

* * *

13 1 103 21 recall that for more than one loop the magnitude of the torque can be found by

$$\tau = NiSB \sin\theta \ .$$

13 1 104 00 describe the oper[illegible] [illegible]anometer in terms of force o[illegible] [illegible] [illegible]ying wire in a magnetic fi[illegible]

13 1 104 01 recognize that a D.C. motor, a voltmeter, and an ammeter all operate on the same principle.

* * *

13 1 104 21 define a galvanometer as a device for measuring electric currents.

13 1 105 00 describe the operation of a D.C. motor in terms of force on a current-carrying wire in a magnetic field.

13 1 105 01 demonstrate the direction that a single-loop motor will turn.

13 1 105 02 recall that the magnitude of a magnetic dipole moment of a current loop is

$$\mu = NiS \ .$$

13 1 105 03 calculate the torque on current loops in a uniform magnetic field by

$$\vec{\tau} = \vec{\mu} \times \vec{B} \ .$$

13 1 105 04 recall that the potential energy of a current loop in a magnetic field is

$$U = -\vec{\mu} \cdot \vec{B} \ .$$

13 1 105 05 recall that the average value of the torque for a D.C. motor of N loops is

$$\tau = \frac{2NiAB}{\pi} \ .$$

13 2 106 00 answer questions and solve problems involving the circular orbits of charged particles in a uniform magnetic field.

13 2 106 01 recognize that for a charge particle moving perpendicular to a magnetic field,

$$qvB = \frac{mv^2}{r} .$$

13 2 106 02 recall that the frequency of revolution of a charged particle moving in a magnetic field is

$$\nu = \frac{qB}{2\pi m} .$$

13 2 106 03 recall that the radius of the circular orbit of a charged particle moving in a magnetic field is given by

$$r = \frac{mv}{Bq} .$$

13 2 106 04 show that charge particles of equal momenta describe orbits of the same size.

14 1 107 00	describe the magnetic field around a straight, current-carrying conductor.
14 1 107 01	recognize that the magnetic field lines around a straight current-carrying conductor are circular in a plane perpendicular to the conductor.
14 1 107 02	recall that if the thumb of the right hand points in [illegible] direction of the current, the fingers will [illegible] in the same sense as the magnetic field lines.

14 1 108 00 use the mathematical statement of Ampere's law in the solution of qualitative and quantative problems.

14 1 108 01 recall that the symbol i in Ampere's law represents the net current enclosed by the contour of integration.

14 1 108 02 recall that the value of the permeability constant, μ_o, is $4\pi \times 10^{-7} \frac{\text{T-m}}{\text{A}}$.

14 1 108 03 recognize that Ampere's law is

$$\oint \mathbf{B} \cdot d\ell = \mu_o i$$

14 1 108 04 calculate the net current enclosed by a path if the magnetic field in the region is given.

14 1 109 00 derive the equation for B at a point which is a distance r from the center of a long cylindrical conductor whose radious R radius is greater than r.

14 1 109 01 use the current density to determine that amount of current that passes through the circular path of Ampere's law.

14 1 109 02 recognize that if no net current passes through the circular path of Ampere's law, then the value of the magnetic induction is zero.

14 3 109 03 choose the best graph of the magnitude of the magnetic induction as a function of distance from the axis of a cylindrical shell of known inner and outer radii.

14 1 110 00 Analyze problems involving the force between two parallel wires as given by

$$F = \frac{\mu_o \ell i_b i_a}{2\pi d}$$

14 1 110 01 recognize that the magnetic field produced by a wire exerts no force on the wire itself.

14 1 110 02 recall that the magnetic field of one wire is

$$B = \frac{\mu_o i}{2\pi d}$$

14 1 110 03 recall that the force on one of two parallel wires is related to the magnetic field of the other by

$$F = i\ell B$$

14 1 110 04 recognize that parallel currents attract each other, and antiparallel currents repel each other.

14 3 111 00 define the MKS current unit, the ampere, in terms of the force between parallel wires carrying equal currents.

14 3 111 01 recall that one ampere is that current whic' if present in each of two parallel conductors of infinite length and one meter apart in empty space, causes each conductor to experience a force of exactly 2×10^{-7} N/m of length.

14 3 111 02 calculate the magnitude of the force per unit length between parallel conductors separated by 1 m which carry a current of 1 A each.

14 2 112 00 use the expression for the magnetic induction within an ideal solenoid to solve quantative and qualitative problems.

14 2 112 01 recognize that in the formula for the magnetic induction inside an ideal solenoid, n is the number of turns for unit length.

$$(B = n\mu_o i)$$

14 2 112 02 recall that the magnetic induction within a toroid is

$$B = N\mu_o i/2\pi r.$$

14 2 112 03 select the best graphical representation of the magnetic induction on the plane of a toroid as a function of distance from the center.

14 2 113 00 interpret and apply the Biot-Savart law for the magnitude of the magnetic induction.

14 2 113 01 recall that the Biot-Savart law states that

$$d\vec{B} = \frac{\mu_o i}{4\pi} \frac{d\vec{\ell} \times \vec{r}}{r^3}$$

14 2 113 02 use the Biot-Savart law to find an expression for the magnetic induction at the center of a circular current loop.

14 2 113 03 use the Biot-Savart law to calculate the magnitude of the magnetic induction at a point due to a segment of wire.

14 2 114 00 answer questions and solve problems relating directly to Faraday's law of induction.

14 2 114 01 use the unit of magnetic flux, the weber, and the unit of time as the second to find the unit of induced emf to be the volt.

14 2 114 02 recall that Faraday's law of induction is

$$E = -N \frac{d\Phi_B}{dt}$$

14 2 114 03 recognize that $d\Phi_B/dt$ can occur if either B changes in magnitude or direction, or if the area of flux changes.

14 2 114 04 recognize that the density of the lines of induction increases as one approaches the poles of a magnet.

14 2 114 05 recall that the density of the lines of induction increases with the strength of the magnet.

14 2 114 06 recall that a steady state current will not produce a changing flux consequently the induced current will be zero.

14 2 114 07 calculate the electric field at a point inside the region where the magnetic field varies with time.

14 2 114 08 calculate the electric field at a point located at a distance r from the center of the cylindrical region with radius R (r>R) in which a magnetic field $\vec{B}$ is varying with time.

14 2 114 09 calculate the magnitude of the instantaneous acceleration experienced by an electron placed in a time-varying magnetic field.

14 2 115 00 apply Lenz's law to determine the direction of an induced emf in various induction situations.

14 2 115 01 recall that an induced emf is always such that it opposes the change of the current producing it.

14 2 115 02 recall that the induced current will flow in such a direction as to oppose the change that produced it.

14 2 116 00 solve problem using the expression for the magnitude of the induced current in a loop moving in a magnetic field.

14 2 116 01 recall that the induced emf in a loop moving through a magnetic field B at a velocity v is

$$\varepsilon = -B\ell v$$

14 2 116 02 recognize that the current in a loop moving through a magnetic field B at a velocity v is

$$i = -B\ell v/R$$

14 2 116 03 show that the power to move a loop through a magnetic field B at a velocity v is

$$P = B^2\ell^2v^2/R$$

15 1 117 00 derive the defining equation for inductance L, and establish the meaning of the henry as a unit of inductance.

15 1 117 01 establish the relationship between inductance L and flux linkage $N\phi_B$ with i as the current which causes the flux.

15 1 117 02 define inductance L in terms of the emf $\mathcal{E}$ produced by a time-varying current i.

15 1 117 03 calculate numerically the flux linked by the coil when its inductance and current are given.

15 1 117 04 define the unit of inductance in the MKS systems as the henry and show that it is the amount of inductance which will give rise to a self-induced emf of one volt when the rate of change of current is one amp/sec.

15 1 117 05 calculate the inductance of the coil when the applied emf and the rate of change of current through it is given.

15 1 117 06 calculate the self induced emf of a closely wound coil when its number of turns and self-inductance and the rate of change of current through it is given.

15 1 117 07 calculate the emf induced in the coil when the rate of the change of current in the coil and the inductance are given.

15 1 118 00 calculate the inductance of a long solenoid having $\underline{n}$ turns per unit length, length $\underline{\ell}$ and cross section A.

15 1 118 01 recall that the magnetic field in an ideal solenoid is $\mu_0 in$, where $\underline{n}$ is the number of turns per unit length and recognize that the magnetic flux in the solenoid of cross section A is $\mu_0 inA$.

15 1 118 02 from the magnetic flux ϕ_B in the solenoid calculated, obtain the expression for the inductance of an ideal solenoid with n turns per unit length, length ℓ and cross sectional area A.

15 1 119 00	derive the expression for the power delivered when an emf is applied to a device with a self induction L and a resistance R.
15 1 119 01	recall that the electrical power delivered by an emf in a resistor with current i is εi.
15 1 119 02	from the expression for electrical power εi, obtain the expression for the power applied to cause a current rise di/dt.
15 1 119 03	calculate the power delivered when an emf is applied to a device with an inductance L and a resistance R.

15 1 120 00 answe... ...s and solve problems relating to the m... ...nergy stored in an inductance L carry... ...dy current i.

15 1 120 01 recogn... energy must be stored in the magnet... of a current carrying inductance so that ... ...d can induce an emf which can supply ... closed circuit when the current is inte...

15 1 120 02 recogni... the amount of energy lost is (1/2) Li... an inductor with inductance L and current ... ...owed to discharge.

15 1 120 03 calculat... ...mount of energy stored in the magnetic ... when an inductance and a current of an induc... are given.

15 1 120 04 calculate ... ...nergy per unit volume stored in the magne... ...eld in a closely wound solenoid.

15 1 120 05 show that ... magnetic energy per unit volume stored in ... magnetic field in a closely wound solenoid is ...al to $\frac{B^2}{2\mu_o}$.

15 2 12 ... analyze the general RC circuit charging ... tion qualitatively ... quantitatively.

15 2 121 01 ... nize that the amount of work done by the emf ... arge dq is

$$\varepsilon dq = i ... dt + d\ (q^2/2C)$$

15 2 12 02 calculate the value of the resistance R ... a capacitor which is initially charged to V ... is further charged to V and the current in the circuit is given.

15 2 121 03 calculate the change in the energy stored in the capacitor when it is charged from V_o to V.

15 2 121 04 calculate the rate of change of the potential difference across the capacitor when it is being charged from V_o to V and the instantaneous current ... is given.

15 2 121 05 establish that the charge on the capacitor in a charging RC circuit is given by $q = C\varepsilon\ (1 - e^{-t/RC})$ and that the charge will approach the equilibrium either $t \to \infty$ or $R \to 0$.

15 2 121 06 differentiate $q = C\varepsilon\ (1 - e^{-t/RC})$ to find the instantaneous current at time $\underline{t}$ and obtain

$$i = \frac{dq}{dt} = \frac{\varepsilon}{R}\ e^{-t/RC}$$

15 2 121 07 conclude from $i = (\varepsilon/R)\, e^{-t/RC}$ that the initial current in a charging RC circuit is ε/R.

15 2 121 08 state that the product RC for a given circuit is known as the capacitative time constant.

15 2 121 09 show that when the charging time is made equal to one time constant ($t = RC$), the capacitor will assume a charge equal to 63% of its equilibrium value.

15 2 121 10 calculate the total work done when an uncharged capacitor is charged by a constant emf through a resistor to a potential difference V.

15 2 122 00	... pair of charging curves (t and i ... which are carefully drawn sh... ng correct u... on ... axes but for which only ... is given.
15 2 122 01	... time constant of the R. circuit from ... ropriate curve.
15 2 122 02	det... ne... capacitance of the RC circuit from the curves.
15 2 122 03	deter... source emf from the curves.

15 2 123 00 analyze the general RC circuit discharge equ... qualitatively and quantitatively.

15 2 123 01 show that the equation for a discharging ci... is $iR + q/C = 0$ by using the loop theorem.

15 2 123 02 recognize that the charge on the fully charged capacitor varies as $q = q_o e^{-t/RC}$ when it is allowed to discharge and the capacitor charge will be reduced to 37% of its initial char... after one time constant.

15 2 123 03 show that the instantaneous discharge current i at any time t after discharge has begun is ... by $i = -\frac{\varepsilon}{R} e^{-t/RC}$.

15 2 123 04 calculate the magnitude of the current just after the charged capacitor starts to discharge when values of resistance R, capacitance C and em... are given.

15 2 123 05 calculate the magnitude of the discharging current after one time constant.

15 3 124 00 Analyze the general RL current growth equation qualitatively and quantitatively.

15 3 124 01 Write the RL circuit equation for current growth $i = (\varepsilon/R)(1-e^{-Rt/L})$, and state that the quotiemt L/R for a given circuit is known as the inductive time constant of the circuit.

15 3 124 02 show that the quotient L/R has the dimension of time.

15 3 124 03 calculate $\frac{di}{dt}$ in an RL circuit when the induced emf across the inductor and the inductance L are given.

15 3 124 04 calculate the magnitude and direction of the voltage across the inductor in an RL circuit at the instant the switch is closed.

15 3 124 05 recognize that in an RL circuit the current can approach the equilibrium value only if $t \to \infty$.

15 3 124 06 determine the current in an RL circuit after two time constants when values of R, L and ε are given.

15 3 124 07 determine the induced emf across the inductance after two time constants when values of R, L and are given.

15 3 124 08 determine the rate at which the energy appears as Joule heat on the resistor at two time constants in an RL circuit with given R, L and ε.

15 3 124 09 determine the equilibrium current in an RL circuit when a battery is suddenly introduced.

15 3 124 10 calculate the magnetic energy stored in the magnetic field when the equilibrium current exists in the coil in the RL circuit.

15 3 124 11 find the time it takes to reach 90% of equilibrium current in the RL circuit after the switch is closed.

15 3 124 12 find the time it takes to reach 90% of equilibrium energy stored in the inductor after the switch is closed.

15 3 125 ... analyze carefully dr... current- and voltage-decay curves for an ... circuit for which units are given on both ...

15 3 125 01 determine the induc... time constant of the ... circuit from eit... or both curves

15 3 125 0. determine the valu... L for this RL ... cuit using the curves.

15 ... 125 0. calculate the inductance in the RL ... cuit when the resistances are given.

15 3 126 00 analyze the general RL current decay equation qualitatively and quantitatively.

15 3 126 01 state that the equation that describes the decay of current in the RL circuit is

$$i = (E/R)\ e^{-Rt/L}$$

15 3 126 02 show that if one time constant interval elapses between opening the switch and current reading, the current will have decayed to 37% of its initial current.

15 3 126 03 determine the resistance in an RL circuit when the time constant for the decay of current is changed due to a change in the resistance in the circuit.